CHAPTER 2 OBJECTIVES AND METHODOLOGY

2.1 Objectives

The Ministry of Energy (MoE) of Republic of Armenia, in fall 1999 prepared a Draft Least Cost Development Plan. After careful review of this plan by Government agencies and international organizations, the decision was made to expand this plan further and use international consultants' assistance in its preparation.

Hagler Bailly Services, Inc. with USAID approval was assigned to provide consulting services to the Ministry of Energy. The major objective of this study was to carry out a planning study to identify and prioritize technical and financial requirements for the rehabilitation and development of the electric generation power sector. The basic intent of the study is to assist the Government of Armenia to define an appropriate capital investment plan for the power sector through the year 2015. The study took into account strategic needs for relative energy independence, increased supply reliability requirements, and environmental compliance of the different options considered in the plan.

The first objective of the study was to forecast the likely demand for electricity during the next 15 years and to select an optimum mix of major capital projects for generation that would meet the country's needs for electricity in the period from 2000 through 2015. A second object was to provide an annual investment program showing the capital requirements for the rehabilitation and expansion of the country's generation facilities. The third objective was the transfer of technology for power system planning and related methodologies to Armenian professionals engaged in the business of electricity supply. The determination of the individual generation tariffs, as well as average system generation cost, was not a part of the Least Cost Planning Process.

A number of related studies of the Armenian energy and power subsectors were underway or had already been completed by other development assistance organizations. The Study team made appropriate use of the completed work, and coordinated work as closely as possible with other organizations that were active in the field. This allowed the study team to focus on the areas of rehabilitation and construction of new facilities for power generation and to leave other areas such as energy supply security to others.

The Figure 1 below presents a general approach to the study process.

Upon the identification of major tasks, the following analysis activities commenced:

- Data acquisition and study assumptions preparation;
- System demand forecast preparation;
- Fuel analysis;
- Generation system reliability analysis;
- DSM analysis;
- Supply options and screening analysis.

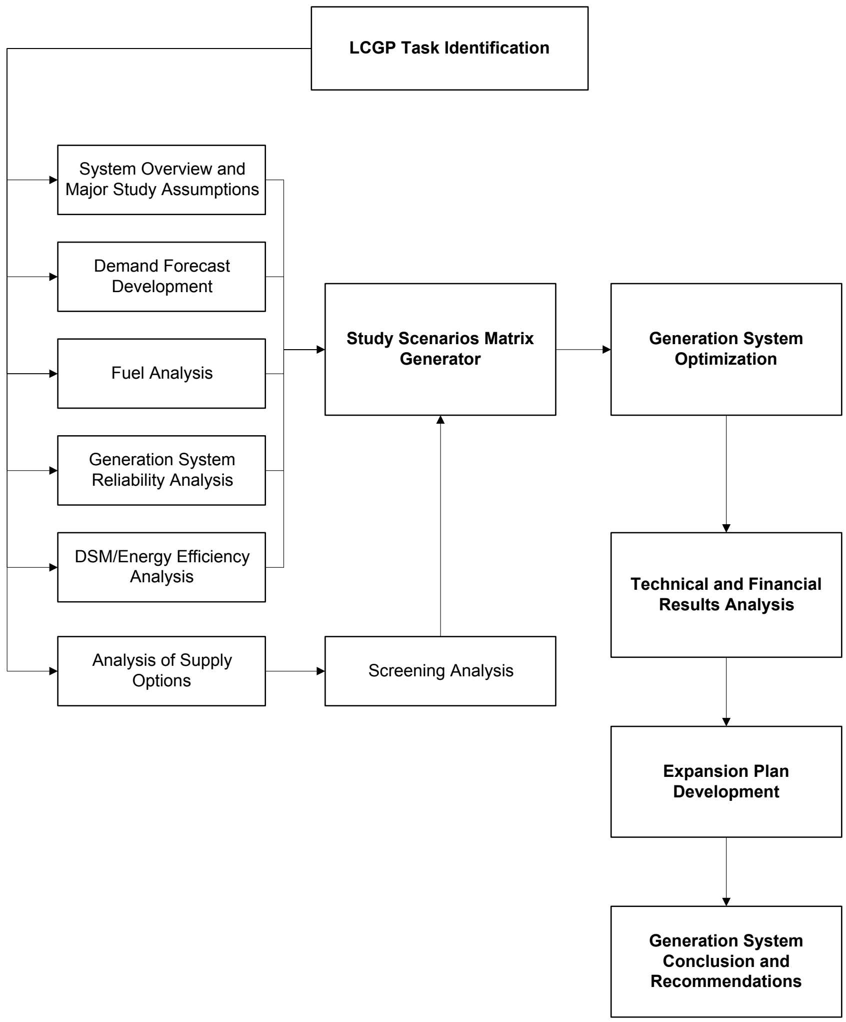

Figure 1 – LCGP Study Approach

2.2 Data Acquisition

Power generation planning requires a wide spectrum of accurate data on different aspects of the electric power system. The quality of the planning results is very dependent on the quality of input data. In this respect this study faced a great challenge, since both availability and reliability of the available data are far from satisfactory. In most cases, the data that was obtained needed additional processing, validation, and comparison with data from other sources.

The complex nature of electric power systems requires the consideration of a wide spectrum of technical, economic and other issues. In the recent transition period many important items of information simply have not been recorded. This has been due to a breakdown in the institutional infrastructure that was previously responsible for data gathering, as well as physical limitations. Currently, as a result of deficiencies in metering and communications equipment, even the dispatchers do not have full information on the system's condition.

Data was obtained from a wide array of sources in Armenia. Ministry of Energy, Ministry of Economics and Finance, Armenergo, and generating facilities provided most of the information on existing plant conditions and operational data. Design institutes such as the Armgazproject and the Hydroproject Institute provided information about prospective gas and hydro projects. Experts from these institutions also provided expertise and advice regarding the quality of available data, which was a valuable contribution to the project.

In many cases the data and results of studies and reports done previously by other agencies were used. This constituted a large part of our initial data set. However, in many cases the data was outdated, and contained inconsistencies and contradictions. Because of this considerable time has been spent on validation and verification of conflicting data sources. In cases when discrepancies between reports and data obtained from the power companies occurred, the latter was used assuming that it was more recent and contained fewer mistakes.

An important component of the data collection and validation effort was a series of monthly coordination meetings, which were conducted in the Ministry of Energy between Government Agencies, donor organizations, and consultants. These were used for both soliciting information from knowledgeable sources and for validation of our data and preliminary findings.

The information on existing hydropower plants was collected mostly from previous studies and from hydropower plants (HPPs). There were studies done by European consultants, Hager Bailly Services, Harza Engineering, Burns and Roe Enterprises, and others. In addition, HPPs' Business Plans were utilized to access the scopes of work for repairs to existing hydro plants. However, HPPs focused mostly on electrical and mechanical parts needing short-term repairs.

Previous studies provided data on the actual physical condition of existing plants and assessments of future plant sites. This included information on turbine wear, stream-flow projections, and sedimentation data for potential plant sites. Historical data on plant performance was obtained from the Dispatch center and different departments of Ministry of Energy. Information on prospective projects was obtained from the International Development Department of MoE, which has performed feasibility studies including the design work construction cost estimates for some major projects currently under consideration. Selected sites were visited in order to verify the data collected from different sources and to assess the general level of their accuracy.

Most of the information on thermal power plants was known from condition assessments done during previous work by various organizations. However, many site visits were arranged in order to assess the conditions of thermal power that had not been previously evaluated. The Report also provides recommendations on future detailed feasibility studies required for power plants.

The information on alternative sources of energy was obtained from several on-going projects, such as ArmNedWind and 3E, GeoEnergy, and Ministry of Energy. Information provided included wind potential and estimates of geothermal potential.

2.3 Demand Forecast

The forecasting procedure employed for this study, along with the set of models for various segments of the market, are presented in Figure 2.

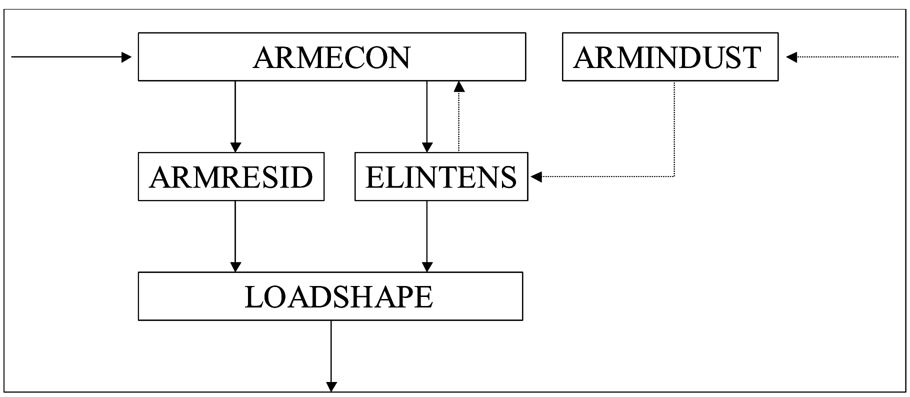

Figure 2. System of models for projecting electricity consumption in Armenia.

A summary of each of these models follows:

ARMECON - this econometric model was built to estimate rates of economic growth as well as the structure of GDP production, based on assumptions on future policy with regard to rates of accumulation and borrowings. The output of this model is used as economic activity input in other modules.

ARMINDUST – initially, this model was intended to take into account future industrial development along with other sectors of the economy in the ARMECON module. However, an analysis of the evolution of GDP production indicates that during 1994-1998, no sustainable industrial development occurred in real terms. Therefore, it is not possible to derive any correlation between investments and level of industrial growth during this time period. For that reason, it was decided to treat industry separately from the rest of the economy, and for different scenarios to make separate assumptions of future industrial growth. Thus, the rate of industrial development does not depend upon the amount of total investments in any particular year. On the other hand, industrial production is taken into account for the calculation of total GDP. Different assumptions are also made about changes in industrial electricity intensity that is related to the rate of industrial growth. This is presented in the diagram by a set of dashed arrows.

ELINTENS – this module was developed to calculate electricity intensities for separate sectors of the economy, to trace historical changes caused by variations in production levels, and to calculate energy consumption on the basis of indicators of economic activity and electricity intensity in each sector.

ARMRESID – this module was developed to take into account possible changes in residential sector consumption patterns caused by changes in economic conditions and the possible restoration of natural gas supplies. Since the share of electricity consumption in households currently exceeds 40 percent of total metered sales, which is twice the consumption of electric power in industry, it is necessary to conduct a detailed analysis of energy uses in this sector.

LOADSHAPE – this module was built to simulate future changes in the total system load curve caused by the uneven development of different sectors of the economy and alterations of consumption patterns inside the various sectors themselves. Load curves used in the modeling process were based on hourly meter readings.

Overall forecast results are expressed as annual values of consumed electric power, the corresponding required amounts of generation to satisfy this demand, and monthly values of system peak loads. More detailed descriptions of each component is contained in the following sections.

Detailed descriptions of the methodology used for projecting electricity demand as well as the results of demand forecast are presented in Chapter 4.

2.4 System Reliability

The calculations of the reserve margin requirement were performed using the sophisticated computer programs which employ the approach of probability convolutions for calculation of the reserve margin. The following provides the major formulas and theoretical approaches used.

The total reserve of active power for the power system consists of two components:

1. The first component is reserve required for current and mid-term maintenance and major overhauls. It is a common practice to conduct routine maintenance and major overhauls of

the power plants during those periods when the customer load is relatively low. The required amount of maintenance and overhauls can be determined as MWh according to the following formula:

$$S_G = \sum_{i=1}^{f} N_i * t_i$$

where,
N_i – total available capacity of i-group of units;
t_i – duration of maintenance and overhauls
f – number of equipment groups.

The reserve for maintenance and overhauls is required only in case if S_G is bigger than the overall decrease of customer consumption during the periods of low end-use electric demand (S_L). In this case, the reserve for maintenance and overhauls can be determined according to the formula below:

$$\mathrm{Reserve}_{M\&O} = \frac{S_G - k * S_L}{12}$$

Where, k (as per Russian norms) is assumed to be equal to 0.9-0.95

2. The second component is operating reserve. There are three factors which impact the value of required operating reserve:

   - Reserve to replace equipment in forced outage;
   - Reserve to compensate deviations of the load;
   - Reserve to secure error in load forecast.

Optimal operating reserve can be determined by minimizing the goal function consisting of three components:

- Construction cost of reserve capacity;
- Cost to maintain reserve capacity;
- Total loss for consumers due to blackout given the pre-defined value of load loss.

For optimal operating reserve the integral probability of capacity deficit is equal to:

$$J_{OPT} = \frac{\beta}{a * T}$$

where,
β - discounted cost for construction and maintenance of reserve capacity for period T;
a – value of loss load for consumers.

Optimal operating reserve is defined by the following criteria:

$$J_{(r-1)} > J_{OPT} \geq J_r$$

where,
$J_{(r\text{-}1)}$ and J_r are integral probabilities of capacity deficits for (r-1) and r MWs of operating reserve.

The goal function is optimized during the run-time of computer program that calculates the optimal operating reserve. More details on methodology and computational conclusions for reliability analysis are presented in Chapter 7 of the Report.

2.5 Fuel Analysis

Fuel analysis was focused primarily on identifying potential fuel sources for power production and forecasting its consumption and price escalation patterns. Additionally, fuel diversification options were preliminary explored and the results were incorporated into the Least Cost Plan. The results of analysis of fuel supply options were used as important components of input data package for modeling.

Natural gas has been identified as the primary fuel to be used by the Armenian power sector in the foreseeable future. Three types of gas were considered and two escalation scenarios were applied to each of these fuel types during the modeling. The first type is natural gas currently imported to Armenia through Russia, which is paid mostly in barter. Natural gas paid in cash represents another type, which is assumed to be a fuel for new prospective (IPP) units. The third type of gas was modeled as a fuel mix currently burnt by Yerevan TPP. About 20% of total gas volume consumed at this power plant is synthesized gas with lower heating value as compared to prior two types.

Two major factors were considered for natural gas price forecast. The first one is based on proposition that the world trend of natural gas price may not be directly applied to the situation in Armenia. Secondly, the assumption was made that some competition is expected on the Armenian gas market due to the fact that a number of countries neighboring Armenia have vast gas reserves. Current natural gas consumption patterns and the forecast by Armgasproject and ERC, as well as implementation of the Armenian gasification program were also analyzed.

A number of diversification options were explored within the limits of available data, including gas supply from Azerbaijan and gas pipeline from Iran. A currently proposed high price of Iranian gas cannot be considered as viable alternative gas option for Armenian thermal power plants. However, the price negotiations taking place now should continue to bring the gas price to competitive level.

Since there was no access to detailed data concerning nuclear fuel, the information used in the current Least Cost Plan was based on official reports published by other Consultants. Coal and mazut fuels were also assessed and analyzed.

2.6 Screening Analysis and Supply Options

Screening analysis is an essential part of the overall modeling process. Screening reduces the number of supply options to be considered at the stage of computer modeling, reducing computational time and increasing the optimization accuracy. The screening process implies the determination of screening curves, which take into account capital costs, fuel costs and fixed and variable O&M costs, expressed in annualized dollars per kW against various load factors. The objective is to select the technologies with the lowest life cycle unit costs.

A number of potential technologies that passed through screening process were divided in two different categories. The first group of options (called "economic supply options") was used to determine the expansion plan for Armenian generation sector on the purely economic basis, i.e. minimum system cost as the main criterion. The second cluster of options (called "strategic supply options") contained a number of technologies that would ensure Armenia's electricity supply from the perspective of national security disregarding the economic costs.

2.7 Optimization Process

The Wholesale Integrated Planning Model (IPM™) of ICF Consulting, Inc. is a long-term optimization dynamic planning model that uses linear programming formulation to select investment options and to dispatch generation and load management resource to meet overall electricity demand and energy requirements. The dynamic nature of the model implies the capability to use forecasts of future conditions, requirements and option characteristics to make decisions for the present.

The model is extensively used throughout the world by private companies and government agencies in the areas of integrated resource planning, detailed modeling of dispatch, strategic planning, options assessment, optimization of utility operations under system-wide constraints, estimation of avoided cost, and analysis of uncertainty.

IPM™ is a fully integrated software package, consisting of a number of modules. In IPM™ all its modules are governed by a single main driver of the program, that automatically initiates operation of each of the modules. The IPM™ core module writes the linear programming task in the output file that is processed in the next step in the linear-programming solver (XPRESS MP by Dash Associates, Inc.).

The optimization criterion in IPM™ is minimization of the present value of the total costs of the simulated power system in the entire time horizon, which includes:

- Production cost of electricity and centralized heating generation;
- Capital investments into new power plant and transmission line construction and existing facility rehabilitation during the planning interval years. The capital investments are included in equivalent form as annuities that are calculated as part of total investment at fixed payments on capital;
- The minimized sum also includes costs and revenues associated with electricity purchases and sales outside the energy utility and energy efficiency project costs.

The major groups of constraints include:

- Meeting the demand for electricity in each year, season, region and load segment;
- Maintaining necessary level of reliability of the regional sub-systems;
- Constraints on inter-regional transmission;
- Environmental emission constraints;
- Fuel availability.

Minimization of total production and capital costs under the given set of constraints ensures objective, commercially optimum dispatching (utilization) of available generating resources to meet balance conditions, as well as the commissioning of new resources in view of service-life efficiency.

One important feature of the model for the purposes of the study is its capability to describe existing power plant rehabilitation and upgrading processes. IPM proposes algorithms for the timing and specific rehabilitation methods for optimization of each facility.

2.8 Investment Planning

The IPM optimization modeling provided results in terms of optimized capacity and investments requirements for the time interval of 2000-2015 with a run-out year 2020. Optimizing for this 15 year period, instead of on short-term basis, allowed for the consideration of more options and for a clearer definition of optimum long-term solutions for the power system's development.

However, the IPM multi-year optimization approach does not provide integral unit solutions when optimizing the schedules of capacity additions due to a specific linear programming technique that it employs. To "convert" these non-integral MW-based initial model's outputs into the discrete unit-based capacity additions, subsequent analysis using iterative IPM model runs is required.

Once an optimum solution or set of alternative solutions has been identified, the IPM model can be reapplied on a year-by-year basis, to provide output in terms of annual capacity additions. These results can then be used to develop annual capacity expansion plans and capital investment forecasts. However, the model was constrained to require that specific generating plants, or major portions of generating plants, be commissioned in specific years. The commissioning dates were established by aggregating the gradual commissioning sequences from the original optimized results into single mid-span years. The IPM model was then run again to verify that the adjusted results conformed to the original optimized model results. Multiple IPM model runs were conducted iteratively to develop a set of plant commissioning dates that closely reflected the optimization results in terms of life-cycle NPV cost.

The annual commissioning schedules were then used to determine annual capital expenditures that will be needed to meet the meet the required start-up dates. This was done by entering the annual construction costs for specific plant facilities into a spreadsheet, and tallying the costs for all of the plants on a year-by-year basis.

2.9 Sensitivity Analysis

The sensitivity analysis was conducted to assess potential impacts of electricity load forecast, Armenian Nuclear Power Plant decommissioning date, fuel price forecast and discount rate on Armenian generating capacity expansion plan in terms of technology, timing, and economic costs. Given this set of factors, two matrices of study cases were developed: one for economic supply options and the other for strategic options. Additional sensitivities were analyzed to verify economic benefits of the combined-cycle CHP unit at Yerevan TPP at different steam demand levels.